TUNNELING ACCELEROMETER MULTICHIP MODULE
(Integrated Sensor)

THIN FILM TECHNOLOGY RADIATION HARDENED MCM

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Abstract-

This paper summarizes and reports a radiation hardened Spacecraft Integrated Sensor/Circuit Technology that has been delivered for flight applications to be flown on board STRV-2 (Space Technology Research Vehicle-2). It also describes the design, development, fabrication and operation of all elements of the Tunneling Sensor. Tunneling Accelerometer Integrated Sensor/Circuitry is the first flight-ready demonstration of electronics as part of electron tunneling sensor. It is a radiation hardened spacecraft MCM [1] Integrated Circuit (IC) technology to operate between -40 & + 70 Degrees Celcius in a 100 Krad (Si) environment. Circuit with the sensor is the first micro-electromechanical system (MEMS) based on electron tunneling principal. Circuit guarantees automatic tunneling by adjusting tunneling gap (~ 10 Angstroms) at above mentioned environments with minimum power consumption.

1. Introduction

Devices employed in measuring physical quantities such as position acceleration temperature etc. rely on conversion of the physical quantity to a change in the relative separation between a pair of components. Changes in relative position are then detected often requiring large structures to achieve sensitivities that are not limited by readout noise in the transducer.

Recently, electron tunneling through a narrow vacuum barrier has been employed in scanning tunneling microscopy (STM) to study the atomic scale structure of surfaces. The tunneling current I has the following dependence on the separation between a pair of metallic electrodes s:

$$I = V e^{(-\alpha(\sqrt{P}s))}$$

Where P is the height of the tunneling barrier, V is the bias voltage, V is small compared to P, and $\alpha = 1.025$. This sensitivity to relative position is superior to that available in other compact transducers and creates an opportunity for miniaturization of a broad class of sensors without loss of sensitivity.

Since the tunneling current varies exponentially with displacement, the transduction process is not inherently linear. In addition, it would not be practical to try to maintain an average electrode spacing of a nanometer passively. Consequently, the tunneling transducer is operated as a closed-loop device where the tunneling current is used to adjust the tunneling gap. The feedback maintains a constant tunneling current (and, therefore, a constant gap) and the output signal is the feedback control voltage rather than the tunneling current. By maintaining a constant gap, the system is actually dependent on the differential behavior; a small-signal linear response is obtained instead of the large-signal exponential response[7].

In tunneling devices, an analog feedback circuit compares the measured tunnel current to a set point and adjusts the separation between the tunneling electrodes with an electromechanical actuator. Typical tunneling devices rely upon piezoelectric actuators. These actuators are known to suffer from sensitivity to thermal drifts, hysteresis; these effects can impose limitations on the performance of existing tunneling devices.

2. Tunneling Accelerometer Multichip Module:

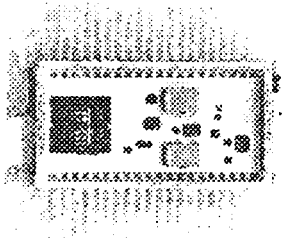The Tunneling Accelerometer Sensor Multichip Module in Figure 1. below

Figure 1. Tunneling Accelerometer Multichip Module

incorporates a mechanical tunneling device and its electronics control circuitry. It is a mechanical sensor which is made by silicon processing using Tunneling Displacement Transducers. The STRV-2 Tunneling Accelerometer uses displacement transducer to detect Gravitational force Accelerations. The sensor itself consists of a tip and a membrane essential for the tunneling action (Figure 2). The third electrode (deflection electrode) along with the closed loop

Figure 2. Micromachined silicon Sensor

operation of the electronics helps to maintain the tunneling action.

Maintaining the tunneling action is essential for the detection of any force acting upon the accelerometer membrane. A control voltage is applied to the deflection electrode through feedback control circuit (Figure 3).

Micromachined Infrared Detector Electronics
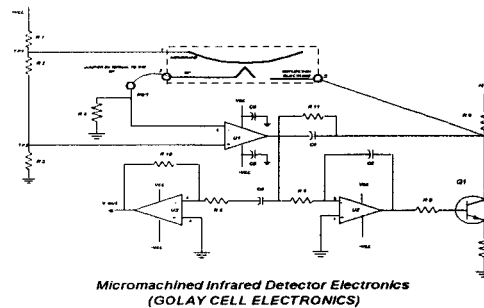(GOLAY CELL ELECTRONICS)

Figure 3 Schematic Diagram of Accelerometer Radiation Hardened Electronics

This voltage is large enough to keep the lower membrane within 10 Angstroms from the tunneling tip. The result is tunneling current which is detected by the feedback circuit. The control of the deflection electrode voltage is accomplished by a slow integrating action of a long time constant integrator which in turn controls the base of the loop transistor. Controlling the current through the transistor invigorates the servo action and keeps the tunneling action steady [2,3]. The electronic parts in the circuit were chosen to survive 100 Krad (Si) environment.

The advantages to the development of sensor components in silicon include the use of single crystals as raw material, use of photolithography for precision patterning, and use of batch processing techniques to reduce fabrication costs.

Micromachining has been used in this case to produce micron scale components with micron scale precision.

In contrast to conventional tunneling devices, the relative position of the electrodes is controlled through the use of electronic servo loop system of electrostatic forces applied between the elements. The electron tunneling displacement transducer, was the first such device to use a quantum mechanical tunneling current to detect changes in separation between a pair of sensor elements [4]. The original devices consisted of piezoelectric actuators supported by complicated mechanical structures. More recently complete tunnel sensors have been fabricated from micromachined silicon components. The separation between the tunneling electrodes is controlled by electrostatic forces between a pair of metallic electrodes .

3. Fabrication:

In general the wafers have been polished on both surfaces and are coated with > 0.5um SiO_2 which is patterned by standard photolithography techniques. The wafers are etched in ethylene diamine pyrocatechol (EDP), removing the parts of the silicon wafers not covered by SiO_2 mask. After etching, the remaining oxide is removed in a buffered HF etch. A new oxide layer > 1um thick is then grown on all surfaces of the structure. Gold electrodes are thermally evaporated onto the components of the sensor through shadow masks which have been fabricated by the same micromachining techniques. The SiO_2 serves as a dielectric isolation layer between the metal films and the silicon substrate.

Photolithography, micromachining and metallization techniques are used to fabricate the components.

4.0 Discussion:

The Tunneling Accelerometer itself has been exposed to direct gamma radiation with Co-60 radiation source at Total Dose Radiation of 100 Krad(Si) in JPL Radiation Test Chamber along with the electronics supporting the tunneling action. During this process tunneling has been monitored assiduously. Dynamic action of turning the tunneling action 'on' and 'off' while radiating the accelerometer was also performed. In both cases tunneling was not effected by the radiation source.

Hybrid circuit advantages over custom monolithic IC in this case were:

1. Power Packaging
2. Lower nonrecurring design and tooling costs for low to medium volume production
3. Readily adaptable to design modifications
4. Fast turnaround for prototypes and early production (i.e. this particular project had 75 day flight delivery schedule)
5. Higher performance sub-components available, for example +/- 0.1 % resistors, +/- 1% capacitors and low TCR zener diodes
6. Ability to intermix device types of many different technologies, leading to increased design flexibility
7. Ability to rework allows complex circuits to be produced at reasonable yields, and allows a certain amount of repair.

The Integrated Sensor with its power packaging described above has been delivered to be flown on board Space Technology Research Vehicle (STRV-2) for the purpose of demonstrating a tunneling action in space environment.
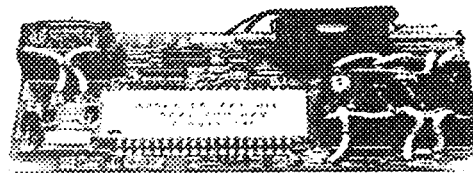
Figure 4. The Tunneling Accelerometer and its support electronics.

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